HIGH PERFORMANCE SCALABLE CAPACITY CONSTRAINED ROUTING ALGORITHMS FOR EVACUATION PLANNING

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ABSTRACT

Capacity constrained route planning tools are vital for increasing the survivability of troops in battlefields and for homeland defense preparation. Efficient tools are needed to produce plans which identify routes and schedules to evacuate affected population. We propose a novel route-scheduling tool for evacuation route planning.

1. INTRODUCTION

Capacity constrained route planning tools are vital for increasing the survivability of troops and increasing lethality of weapons. Lethality of our weapon may be increased via identifying critical transportation infrastructure (by route analysis algorithms) to be destroyed to corner enemy units. It is useful to increase the survivability of our troops in urban warfare by evaluating plans of action so that troops are not cornered in a flank attack or in an alley and trapped soldiers are rescued in a timely manner (e.g. Mogadishu, Somalia). During an combat mission, route planning tools can be used to compute possible alternate routes of the enemy that need to be blocked and to compute the evacuation egress route of troops in case of an accident. In a homeland defense scenario, it can be used to compute evacuation routes for affected population in case of terrorist attack. Therefore, efficient route-scheduling tools are needed to produce plans which identify routes and schedules to evacuate affected population to safety. In this paper, we propose a novel route-scheduling tool for evacuation egress route planning.

2. PROBLEM STATEMENT

The capacity constrained routing problem can be formulated as follows. Given a transportation network with capacity constraints, the initial number of evacuees with initial locations, and evacuation destinations, we need to produce evacuation route plans consisting of a set of origin-destination routes and a scheduling of people to be evacuated via the routes. The objective is to minimize the total egress time for evacuation. The scheduling of people onto the routes should observe the route capacity constraints. A secondary objective is to minimize the computational overhead of producing the evacuation plan.

3. RELATED WORKS

The current methods of evacuation planning can be divided into two categories, namely traffic assignment-simulation approach and route-schedule planning approach. The traffic assignment-simulation approach, such as DYNASMART (Mahmassani et al, 2001), conducts stochastic simulation of traffic movements based on origin-destination traffic demands and uses queuing methods to account for road capacity constraints. However, it may take long time to complete the simulation process for a large transportation network. The route-schedule planning approaches tend to use more sophisticated network flow and routing algorithms. Hamacher and Tjandra (Hamarcher and Tjandra, 2002) gave an extensive literature review of linear programming algorithms. These algorithms produce optimal plans for small size networks. However, it cannot scale up to large size transportation networks due to high computational running time. Heuristic route-scheduling algorithms can be used to find sub-optimal evacuation plan with reduced computational cost. However, current naive heuristic approaches only compute the shortest distance path from a source to the nearest destination without considering route capacity constraints and traffic from other sources. It cannot produce efficient plans when the number of evacuees is large and the road network is complex.

4. OUR APPROACH

New heuristic approaches are needed to account for capacity constraints of the evacuation network. We propose a new heuristic algorithm, namely Capacity Constrained Route Planner (CCRP), to solve the evacuation planning problem. We model capacity as a time series and use a capacity constrained routing approach to incorporate route capacity constraints. This algorithm can divide evacuees from each source into groups and assign route and time schedule to each group of evacuees based on the destination arrival time of the quickest route re-calculated in each iteration. Our approach reserves route capacities subject to the capacity constraints. We model edge capacity and node capacity as a time series instead of fixed numbers. A time series represents the available capacity at each time instant for a given edge or node. We propose a heuristic approach based on an extension of shortest path algorithms (Corman et al, 2001) to account for route scheduling with capacity constraints. The CCRP algorithm is an iterative

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approach. In each iteration, the algorithm first searches for route ***R*** with the earliest destination arrival time from any source node to any destination node, taking previous reservations and possible waiting time into consideration. Next, it computes the actual flow amount of ***f*** evacuees that will travel through route ***R***. This amount is affected by the available capacity of route ***R*** and the remaining number of evacuees. Then, it reserves the node and edge capacity on route ***R*** for ***f*** evacuees. The algorithm continues to iterate until all evacuees reach destination. Performance evaluation on various network configurations shows that the proposed CCRP algorithm produces high quality solution and at the same time significantly reduces the computational cost compared to optimal solution algorithm. Experiments show that the new algorithm is also scalable to the number of evacuees and the size of the transportation network.

5. A CASE STUDY

We also conducted experiments using a real evacuation scenario. As shown in Figure 1, the Monticello nuclear power plant is about 40 miles to the northwest of the Twin Cities. Evacuation plans need to be in place in case of accidents or terrorist attacks. The evacuation zone is a 10-mile radius around the nuclear power plant as defined by Minnesota Homeland Security and Emergency Management. A hand-drafted evacuation route plan was developed to evacuate the affected population to a high school. However, this plan did not consider the capacity of the road networks and put high loads on two highways. We conducted experiment using our CCRP algorithm. The experiment was done using the road network around the evacuation zone provided by Minnesota Department of Transportation, and the Census 2000 population data for each affected city. The total number of evacuees is about 42,000. As can be seen in Figure 1, our algorithm gives much better evacuation route plan by selecting shorter paths to reduce total evacuation time and utilizing richer routes (routes near evacuation destination) to reduce congestions. The old evacuation plan has an evacuation egress time of 268 minutes. Our algorithm produced a much better plan with evacuation time of only 162 minutes. This case study shows that our algorithm can be used to improve existing evacuation plans by reducing total evacuation time.

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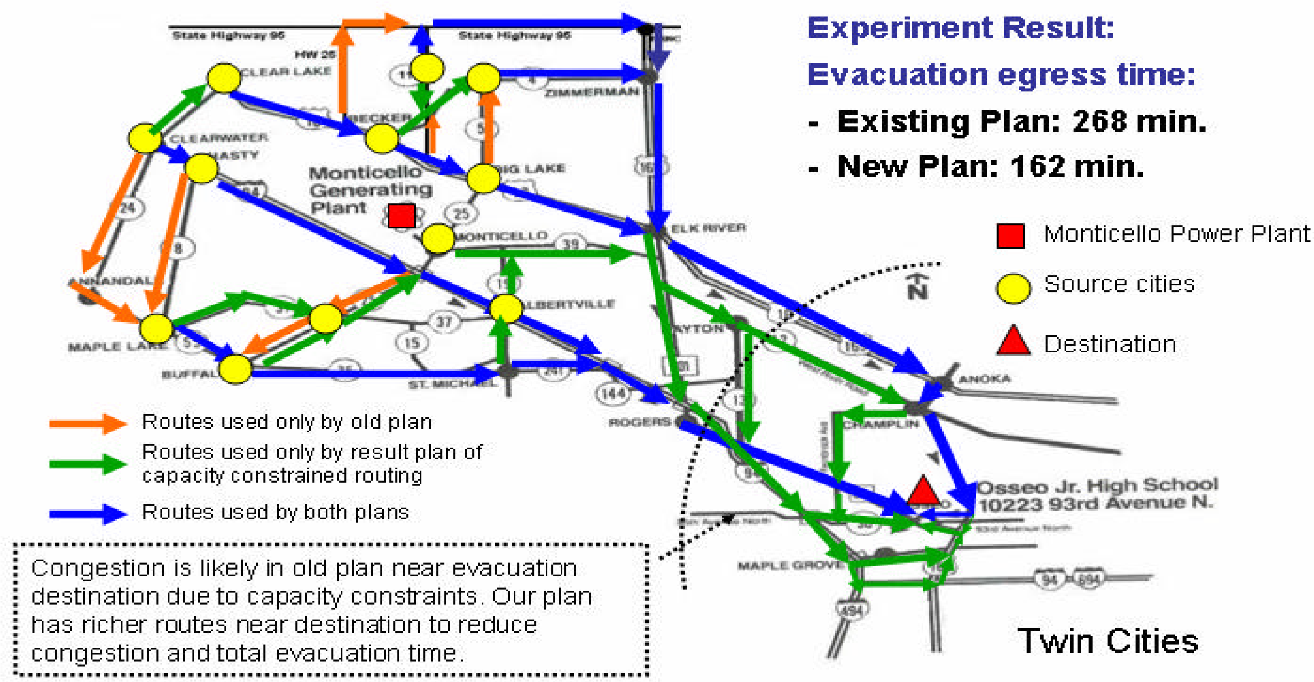

Figure 1: Routes Overlay of Monticello Power Plant Evacuation Planning